US LHC Accelerator Research Program Advisory Committee Review, 10-12 May 2006

Introduction

The Advisory Committee met 10-12 May 2006. Committee members Chao, Devred, Galayda, Minervini, Rode, Seryi, Wittenburg and Yamamoto were present. The Committee was charged to evaluate the program with regard to:

1. Strategic goals
- Potential diversification of Magnet R&D beyond the 09 “technology demonstration” goal
- Cohesiveness of the Accelerator Systems program
- Potential new tasks and partnerships

2. Program execution
- Progress of the Magnet R&D and Accelerator Systems programs
- Are milestones sufficiently well defined?

3. Management issues
- Ensuring excellence in beam commissioning
- Documentation of mutual understandings between LARP and CERN, and within LARP.

The committee was also given latitude to pursue, and to offer comments and recommendations on, any other items which it deems important to the success of the program.

The Committee was impressed with the achievements of the Collaboration in the past two years. The LARP research program demonstrates excellent focus, a strong spirit of cooperation and the clear evidence of synergy within the Collaboration.

General Responses to the Charge

Strategic Goals

The focus of the magnet program has improved remarkably since the last review. The Committee endorses emphasis on understanding the properties of the conductor and on development of a long quadrupole prototype by 2009.

Interesting and important opportunities for diversification of the program were presented; however diversification in magnet R&D should be postponed beyond 2007; in other areas, diversification may be warranted; however care must be taken to avoid greater risk to programs already in progress.

The accelerator physics program is pursuing the development of critical systems for early operation and optimization of LHC: the tune/coupling feedback, the luminosity monitor and the Schottky pickup. The chosen items are well suited to support the strategic goals of LARP. These devices must be delivered in time to support LHC commissioning. The devices are also important in that they are at the foundation of the LARP beam commissioning effort. Timely delivery of these critical systems must be made a highest priority of the LARP program.

Expansion of the program to new tasks and new partnerships, perhaps with universities, is a worthwhile goal. Perhaps support from NSF could be sought in the form of graduate fellowships, postdoctoral appointments and research grants or summer stipends for faculty. This form of support would be an ideal complement to the DOE-supported effort already in place.

Program Execution

Regarding preparation for the DOE review, the committee makes the following observations:

A tremendous amount of important and interesting technical information was presented to LARPAC. For a DOE review, however, the presentations must be shortened or else broken up and scheduled more realistically. It is most important that the overall strategy of the magnet program be presented in a more succinct way. The overall strategic goals of the magnet program (demonstration Nb_3Sn technology in a long quadrupole by 2009) were clearly articulated in a compelling fashion. The progress to date, plans for the future and the argument for funding of the various efforts would be most effective if they are presented in a way that demonstrates the essential importance of each activity to its successor activities, and hence to the overall goals of the program. Ideally, this would take the form of flowcharts that demonstrates the way that each activity of the magnet development program is structured and scheduled to provide information essential to "branch point" decisions determining subsequent steps, leading to achievement of the overall goals for the magnet program. If this is done successfully, the case for timely funding of all proposed efforts will be most convincing. Conversely, the case for overall funding will be weakened if the logic or scheduling of the individual efforts does not convincingly support the overall goals.

Beam Instrumentation Development and Implementation

The comprehensive presentation of the instruments was welcome.
The feeling of the committee is that the three selected instruments supported by LARP are well chosen. All instruments based on solid experience at US accelerators and they have a very good support at US accelerators.

Schottky Monitor

Even though the Schottky monitor is not necessary in the beginning of LHC it provides a lot of very important additional non-invasive measurements of beam parameters which are important for successful commissioning of LHC (Tunes, Momentum spread, Chromaticity, Emittance) on an individual bunch basis. The committee acknowledged the fast and good progress of this task: The final production of the monitors (one for each beam, a CERN task) can start after the final design review in June. LARP already delivered a complete set of construction drawings to CERN. We cannot see any serious obstacles in the building of the monitor by CERN or in the analog processing electronics The interfaces between the monitor and analog and digital electronics seem very well defined, including installation, cabling, and the integration with the control system. We support the proposal to test the compete chain of analog and digital electronics in the US Labs together with a well defined interface to the control system. Special care should be taken to ensure that the required specifications of the timing signals will be met by CERN. Concerning the commissioning of the monitor, the planned two trips to CERN might be sufficient if there are no unexpected problems; however a third trip might be useful to ensure a final commissioning with beam in cooperation with the beam commissioning group of LARP.

A detailed list of milestones up to the first energy ramps and beam stores in LHC should be made available.

Lumimonitor

Based on the written requirements and specifications, the design chosen for the Lumimonitor seems adequate to the Committee. We note with pleasure that the final design is complete and that the fabrication process is defined. The proposed tests at RHIC with protons (250 GeV) and with Au should be supported by the LARP management. The committee encourages the use of electronics boards developed for LHC experiments and welcomes this kind of collaboration. Radiation damage tests should be done with high priority. The tolerable radiation level to passive and active components should be worked out more thoroughly to ensure an adequate lifetime of the components without any failure.
However the Committee repeats a comment from the 2004 review: more information on the expected background would be reassuring to the LARPAC.

The planned 8 FTE-month spent at CERN in integration activities seems adequate. A very good collaboration with the CERN TS/LEA group is mandatory for a successful installation and operating of the monitors. The proposed milestones for FY06 – FY08 seem reasonable but more milestones should be added to bring focus on the first Lumi-measurements at LHC.

Tune and coupling feedback

The committee congratulates the team for achieving the world's first simultaneous tune and coupling feedback that was demonstrated in RHIC. This success shows how LARP can create the environment necessary to ensure a highly productive collaboration. The success of this demonstration gives confidence that the chromaticity feedback during snapback can be controlled at LHC. However, the committee felt that an additional feed-forward and/or a reference magnet might still be considered, to control the LHC in the snap-back regime. These measures are not currently under consideration by LARP.

The LARP management should support the efforts to solve the remaining uncertainties like phase losses and 60 Hz lines from the mains, so that the schedule for finalizing the system design by end of the summer 2006 can be reached. The milestones for FY06 and FY07 seem adequate but additional milestones should be identified, extending to the first energy ramps of LHC (~ 2009). Strong attention should be made to reach the goal of a system test at the CERN SPS.
It is strongly recommended that a complete data acquisition chain be implemented at the LARP Labs to improve the LARP experience with the DAQ system as well as with the software/firmware.

General Comments on Instrumentation

- The documentation and approval plans for each instrument are in a good shape. Indeed there is strong and encouraging evidence for improvement in all aspects of communication and cooperation, within LARP and between LARP and LHC.
- It is most helpful for the instrumentation program that the data acquisition platform be defined by CERN and common to all LARP instruments. This ensures an effective programming of the hardware (e.g. FPGA) and of the interface to the control system.
- A list or inventory of sufficient spare parts for each instrument should be provided to CERN by LARP.
- Written procedures for failure and emergency handling of each instrument should be prepared. This should include identification and training of responsible colleagues at CERN.
- The "passive" instruments, i.e. Schottky monitor and Luminosity monitor are ideal candidates for the LHC@FNAL approach to enhance the experience with remote controlled devices from LARP sites. Therefore a very close collaboration with the LHC control group is recommended.

Machine Commissioning, Hardware and Beam

The committee is pleased to note a good overall progress with preparation of commissioning and organization of the commissioning team. LARP presence at CERN for the IP commissioning will start in six months, and the first person (Peter Limon) is already at CERN for hardware commissioning. The latter has helped significantly in communication and preparation of commissioning. Average presence at CERN in the middle of 2007 will be 7 people.

A lot has been done to ensure that LARP personnel will be fully integrated into the commissioning team at CERN, so that it may work efficiently. In particular, leaders for the IP and hardware and for the beam commissioning have been nominated. The commissioning oversight team has been appointed. The commissioning task lists are used to match the skills of the team with commissioning needs. The LARP commissioners will join a CERN group and receive "project associate" status, which should help them to become a part of the team. The LARPAC recognizes and endorses the need for formal handover and acceptance of hardware to LHC, to clearly define the fulfillment of its obligations. However *the committee suggests that it may be appropriate to document the agreements on commissioning organization, including details of how the experts who developed and built hardware will continue to be involved in assessment of the performance of this hardware after commissioning.*

One of the LARP challenges is to select the best candidates for the best commissioning team, having in mind the long term goals of US accelerator and HEP programs. Online forms are available which facilitate application process from individuals. *A lot depends in this case on the good will of the laboratories, which are expected to agree to free up some of their best people and also ensure their smooth return after the commissioning would finish.* The laboratories have made varying degrees of commitment to support hardware commissioning. FNAL has committed 4-7 people, and LBNL has committed 2-3. BNL will decide on commitment of individuals on the case-by-case basis and SLAC has not yet made a commitment to participate at the time the request was made. *The committee feels that exploration of possibility for US labs to participate in beam and hardware commissioning might have not done exhaustively and suggests repeating the attempt.*

The committee also suggests that applications for the Toohig fellowships should be processed more expeditiously. The Committee would like to make an observation that this very worthwhile program seems to need more managerial streamlining. Given the fact that getting good postdoctoral candidates is always a competitive business, the LARP response to applications has been sluggish, possibly due to the additional complication of communications between the individual laboratory and LARP. It is suggested that the procedure of Toohig fellowship application be substantially streamlined in the future. The goal should be so that nominally the procedure from application reception to fellowship awarding/rejection can be completed in 3 months, and can be shortened in special cases. The Committee maintains that this is necessary in order to reach the best of candidates.

One of the challenges of the LARP program is to make sure that people in commissioning team are familiar with the LHC control system and with details of the ongoing program before arrival to CERN. It has been suggested that the "remote access center", LHC@FNAL, although not part of LARP program (was primarily intended for CMS), may be useful for this purpose. *In committee's opinion, the challenge here is to make sure that LARP personnel really use this facility. The successful and productive use of this access center will be severely damaged unless its users are authorized to take active control of the accelerator. The use of this access center must be actively encouraged in every way; otherwise it can have a negative impact on the image of the LARP program in particular and in general for future international projects. The worst scenario is if the room would stay empty and not actively used. Not of the least importance, the US team while still in US, must participate actively in the remote commissioning meetings and be really engaged, so that their remote presence should be accepted and indeed considered essential by the CERN commissioning team. An appropriate meeting facility may be needed.*

Collimation R&D Program

Collimators comprise a subsystem of LHC that must protect the detectors and accelerator hardware from damage caused by beam loss and beam abort. LHC will develop a collimation system in two phases. In phase I, carbon-carbon absorbers will be installed to handle the lower currents anticipated in early operation. In phase II, additions and improvements to the collimation arrangement are planned for operation at 10^{34} luminosity.

The: LARP program has addressed both phases of operation, by pursuing three tasks:

1-Develop and test a design for Phase II collimators
2- Use RHIC data to benchmark the code used to predict the cleaning efficiency of the LHC collimation system and develop and test algorithms for setting collimator gaps that can be applied at the LHC

3- Understand and improve the design of the tertiary collimation system that protects the LHC final focusing magnets and experiments

A new task has been proposed:
4- Use the facilities and expertise available at BNL and FNAL to measure the effects of radiation on the properties of the materials that will be used for phase 1 and phase 2 collimator jaws

Task 1 has been delayed by manpower shortage, but is making progress since a newly hired engineer was dedicated to the task.

Task 2 has, after early promising results in 2005, been hampered by a lack of manpower. Rapid progress is possible if someone can be assigned to the task; *however this task is relevant only if it can make significant progress prior to the earliest phases of LHC operation*, at which time emphasis should shift to analysis of data from LHC rather than RHIC

Task 3 is underway can be completed in six months, if the necessary manpower remains engaged.

Task 4 has received some motivation from the surprising and favorable results obtained recently, that indicate the annealing of carbon-carbon, apparently related to cyclic radiation exposure and heating. Tests are planned for other materials such as tungsten and copper. There is also cause for concern about short lifetime of a rotating absorber design, due to evidence of extensive splatter of absorber materials to be used or considered for LHC. Therefore this task can have significant impact on future plans.

Accelerator Physics

Accelerator physics activities have covered a wide range of topics tailored to the LARP expertise as well as LHC needs. A reasonable balance was achieved in the present plan under execution.

Electron cloud study was one of the topics being pursued and its effort level increased from 0.6 FTE to 1.3 FTE as recommended by the Committee in its last review. A significant result obtained in the heat load calculation was that the maximum secondary electron yield must be <1.2-1.3. The next topics to be studied include heat load estimate for 12 ns bunch spacing, 3D simulation with ions, estimate of scrubbing time, emittance growth due to electron cloud, and simulation of the pilot diagnostic bench. The Committee considers the present effort level and the list of the next topics appropriate. It would like to encourage an effort to expand the collaboration to include other laboratories. In particular it seems natural to include SLAC, which has planned a parallel program on electron cloud diagnostics at PEP-II in preparation for the ILC.

As mentioned also elsewhere in this report, a first test of the tune and coupling feedback systems planned for LHC operation were implemented at RHIC, and has been demonstrated to work well. The coupling has been controlled to an impressive level of ~0.0007. The Committee commends the LARP team for this significant progress, and considers it ready to consider a version suitable for implementation at LHC. It further takes this opportunity to reiterate that this success was made possible by the excellent collaboration among the LARP participating laboratories. The Committee commends the LARP management for their efforts in this important regard.

An experimental test of wire compensation for long range beam-beam interaction has been initiated. The compensators are to be installed and tested at RHIC. The Committee considers this concept well worth pursuing and falls very well within the mission of LARP. It looks forward to hearing about the first experimental results expected in 2007.

The Committee was presented some preliminary data of flux jumping of the Nb_3Sn wires, together with the associated fluctuations in magnetic multipoles. The magnitude of fluctuation is not large, and is expected to improve with newer wires with smaller filament sizes, and the present plan is to wait to see what the best wire will offer. The Committee expresses concern of this issue and urges it to be studied more actively. In particular, it would like to point out the unique feature here that the multipoles are not only making a single stepwise change but are undergoing fluctuations in time; as a result, there might be a diffusion effect to be evaluated. The study will therefore consist of both measuring/improving the flux jumping and some accelerator physics studies.

Beam commissioning

The LARP effort in beam commissioning occurs after the IR and hardware commissioning. In the on-going preparation of beam commissioning, it is therefore advisable to also consider the issue of how to sustain LARP participation in the post-commissioning period of LHC beyond 2008-2009. It is suggested that generally the mission could aim toward reaching the design luminosity, but there are detailed issues still to be considered. In this context, one issue that emerges concerns the choices of beam commissioning personnel from LARP. The choices should be made consistently with the post-commissioning goals and topics. Another issue concerns the choice of new initiatives. The choice of new initiatives should also be consistent with the post-commissioning goals. Committee's views on the new initiatives are mentioned elsewhere in this report.

Magnet R&D Program

Overview, Management, Integration and Funding

The primary Magnet goal is "Demonstrate a long strong Nb_3Sn model quadrupole magnet by 2009" (90mm bore, 200T/m, 3.6m long): LQ, Long Quad program.

A secondary and longer term goal is to develop a larger bore and higher field quad; this leads to an interim 2009 milestone: 90mm bore, 250T/m, 1m long: HQ, High Gradient Quad program.

There has been major progress in the past two years:

1. The Subscale 110mm short Quad SQ01 reached 97% of short sample
2. The 90mm Quad TQS01 reached 87% of short sample
3. There is a work-a-round for reducing the impact of flux jumps

The magnet program is 52% of FY06 LARP effort or $5.7M. In FY07&08 there is expected to be a slightly lower percentage due to the LHC commissioning efforts.

The three lab magnet collaboration has made very good progress integrating the effort. At the Jun-04 LARPAC review, good integration of effort by phases existed; e.g. one lab designs, one assembles, and third tests. The stated goal was integration of effort on individual phases; this has been achieved, particularly at the technician level, which has helped to standardize procedures.

For the LARP this has been even more challenging since the base program magnet R&D funding is much larger than LARP funding.

Due to the limited resources in FY05 &06 the 2004 LAPAC recommended:

- "Evaluate the balance between dipole and quadrupole R&D, and between technology development and focused model magnet development."

In response the Dipole magnet effort has been eliminated permitting the Quad program to make good progress. This has also permitted the LQ and HQ programs to start.

The breakdown of the magnet effort is:

42% Model Magnet R&D (TQS & TQC)
33% Supporting R&D (SQ, SR, & LR)
18% Design Studies (LQ & HQ)
7% Materials (Conductor)

The primary development in Nb_3Sn is funded by other programs.

The HEP React and Wind program has been killed at BNL due to lack of funds. The SR (Short Racetrack) magnets are a technology transfer program from LBNL to BNL.

The comment from the last review remains: "The presentation of magnet development plan presented to the committee was difficult to read. It would help to have a Gantt chart and/or a decision tree showing clearly the goals and the deliverables of this program."

Focusing all the effort on 90 mm, which is a "conservative" and reasonable aperture, permits the program to maximize its deliverables.

The next major Milestone is the "Support Structure Decision" in June-07. **<u>Without this down select on schedule there will not be adequate funds for the LQ and HQ programs!!!!</u>**

While the committee supports the concept of diversification, it strongly believes that this would be risky to do in FY07 based on the current scope and available funds. The procedure to add scope should be the same as what we saw for the accelerator effort.

The 2004 LAPAC had two questions for consideration:

- What are the requirements on field quality? Are they compatible with present conductor performance (effective filament size and its reproducibility)? **<u>New:</u>** How do flux jumps affect field quality and can anything be done about them?
- What are the specifications regarding radiation damage? It seems that the combination of high stresses and high radiation dose can quickly degrade impregnated coils. What kind of life-time can we expect from such a magnet?

These questions are now very timely.

The committee concurs with the decision in the past two years to focus "all" resources on mechanical issues. Now is the time to start addressing the two other major issues:

- Field Quality agreement with calculations
- Cross Section requirements for Cryogenic cooling

International cooperation including Japanese contribution or mutual communication/exchange of information may be extended specially in the HQ program. Other advanced superconductors such as Nb_3Al and (HTS) could play an important role.

Materials - Conductor

The magnet program has focused all recent development on the OST RRP 54/61 strand design. Although this may not turn out to be an optimized conductor for the Long Quadrupole (LQ) or High Gradient Quadrupole (HQ) magnets, it has several advantages. Realistically, it is the only commercially available Nb_3Sn strand in production which has reproducible and effective performance in the J_c (12 T, 4.2K) ~ 2400 A/mm^2 range. This allows LARP to proceed to resolve magnet technology issues with a relevant wire, while not requiring the program to get saddled by an excessively costly and resource consuming wire development program. Instead, the program is focusing its limited resources on full characterization of this particular wire type (also with minor layout variations) and further development and optimization of cabling parameters. This wire type will therefore be used in present and future SR, LR, TQ and LQ magnets under development and allow for performance comparison while eliminating the potential strong variability of different wire types or sources. A detailed procurement plan was presented through FY08 which accounts for the quantities needed to maintain the planned magnet development program while also fitting the expected budget profiles. This advance planning is also important to OST so that they may do advanced materials procurement and production planning.

Future advances in strand technology will come primarily from the DOE SBIR program, the DOE Conductor Development Program (CDP), the FNAL Core Program procurement of PIT wire, and by conductor development under the Next European Dipole Program (NED). An advanced strand is also being developed for the EFDA Dipole Program which may have features attractive for LARP applications. The committee supports this practical approach to maintain the core goals of the program, but cautions that any insertion of a newly developed strand into the LARP magnet development activities must be carefully planned so as not to slow down the LQ deliverable milestone or otherwise require excessive repetition of magnet development steps. The committee recommends that the program clearly evaluate the risk of introduction of a different baseline strand in the integrated program, and only introduce it at a stage which minimizes technical and programmatic risk.

The collaboration has achieved a practical solution to the significant low field instability problem which had been affecting the performance of early small magnet tests. The source of the disturbance energy leading to this instability is the excessive flux jumping inherent in these very high J_c strand designs which is, in turn, caused by the relatively large effective filament diameter. The effective filament diameter could be further reduced by drawing the wire to smaller diameter, but the present ~0.7mm diameter seems to be a lower limit, beyond which wire breakage and drawn length become unacceptable. R&D was performed under the CDP by OST on developing strands with larger number of sub-elements. This had the desired effect on reducing the effective filament diameter, but also leads to more wire breakage problems and general reduction of RRR. It was found that the instability due to flux jumping could be reduced or eliminated if the RRR of the copper stabilizer could be maintained at 100 or greater. This is achieved by two methods. First, barrier breakage must be avoided during cabling by control of the cable compaction parameters. Secondly, adjustment of the heat treatment to shorter times, although lowering the high J_c by about 8% also leads to RRR values above 100 and practically eliminates the low field instability. The goal is to increase the instability current limit to about two times the operating current for both the strand and the cable. **The committee strongly recommends that these new design criteria be clearly explained, documented and reported to insure that all further design work proceeds on a common basis**.

The committee members expressed some concern that, although the issue of flux jumping on magnet stability may be at least partially resolved, it has not yet been definitively demonstrated that the effect flux jumps will not seriously affect the field quality. Although some measurements of field quality have been measured, they were taken on a magnet using non-relevant strand, i.e. with d_{eff} much greater than that of the OST RRP-54/61. The committee recommends that future magnet tests include field quality measurements so it can be established whether the flux jumps are serious enough to be of concern, and recommends that the collaboration consider what methods might be used to resolve this issue, if necessary, other than eventual development of high J_c Nb_3Sn strands with effective filament diameters less than 30 μm.

A major near-term goal of the strand R&D program is to be able to predict the performance of the TQ magnet series from single strand data and as affected from cable fabrication. Both strands extracted from compacted cables and strands roll deformed to simulate cable compaction are being tested. So far, the strands extracted from compacted cables are useful, along with micrographic examination, in determining the extent of degradation, although, extracted strand data sometimes exhibits wide scatter. FNAL, LBNL, and BNL all have strand test facilities capable of performing critical current tests over relevant operating conditions. The committee encourages the collaboration members to continue to refine round-robin and benchmark testing to ensure consistency and accuracy of test results.

The collaboration has been evaluating the availability of cable test facilities since none of the three labs has a facility to test cable samples at high fields (10T-12T). FNAL has a 28 kA transformer method for testing cable samples in self field. This is useful as a screening and comparison facility, but does not yield relevant high field data. Options being explored include the FRESCA facility at CERN (10T at 4.2K and 1.9K, with samples pres-stressed at RT, and the 11T split pair magnet at NHMFL capable of applying transverse stress at 4.2K. Unfortunately it is costly and time consuming to prepare the cable samples, cool-down and operate these facility magnets and perform the tests, including additional travel costs. Thus these tests can only be performed on a limited basis. **The committee agrees that testing of cables at relevant field, current and stress conditions would be a valuable tool for bridging the large gap in scaling from single strand performance to magnet performance and encourages the collaboration to continue to seek cost effective methods for testing cables.**

Cabling R&D has led to a successful method of preventing excessive strand and sub-element deformation which often results in damaged filaments and broken tin barriers.

This method entails fabricating the cable slightly oversize, annealing at 200C for 2-4 hours to soften the copper and slightly contract the cable, then re-rolling to decrease the thickness by 25-50 µm. This process makes the cable mechanically stable and reduces the performance reduction.

The committee appreciates these innovative developments to minimize damage to the sensitive and expensive Nb_3Sn strand cable and encourages the collaboration to continue these important R&D steps. Ultimately it might be possible to more accurately predict coil performance from single strand and cable data, so that any deviation of final measured coil performance from prediction can be attributed to the proper factors, for example, magnet stress state, rather than cable fabrication or heat treatment problems.

Materials – Insulation

The magnet R&D program includes development of electrical insulation methods compatible with wind and react magnet fabrication, and eventually with high radiation tolerance. Various methods of using ceramic insulation and binder have been used with several new innovations being introduced into the model coils and by product changes by CTD. So far, radiation tolerance is only being considered under the HQ design tasks where the heat removal and cryogenic design is being analyzed. The committee believes more emphasis should be given to these cryogenic considerations because the overall feasibility of the HQ program will depend heavily on whether it is really possible to remove the very high radiation heat loads with a reasonable design which could possible impact the magnet cross-section.

Radiation hard insulation activities may be introduced in the FY07 plan as a new task. The committee encourages this effort to be included so that further feasibility of the LARP quadrupole development program based on Nb_3Sn magnets can be demonstrated.

Short Model Magnet Program and Main Design Choices

The short model magnet program (SR, SQ, TQ and HQ series) is instrumental to the LARP magnet program in at least three aspects: (1) it enables LARP partners to get hands on experience, which is crucial in order to fathom and master the specific issues of Nb_3Sn technology, (2) the TQ series provide a test bed for a number of variants in the 2D and 3D mechanical designs and (3) the HQ series should demonstrate the feasibility of high performance magnets (with conductor peak field up to ~15 T). The committee first wishes to acknowledge the tremendous efforts being carried out and the good and synergetic team spirit that appears to be developing among the three partners. It also wishes to emphasize that the overall goals and framework of the program seem to be suitable to reach the stated goals. Enclosed are nevertheless a number of comments/recommendations regarding some details of the execution plan.

The committee was presented with comprehensive mechanical design studies and analyses. The program emphasis should definitely be on mechanical and quench performances; however the committee would like to stress that, in the end, the goal will be to build accelerator-class magnets for which field quality is a key issue. Hence, during the design phase, some minimum effort should be devoted to assessment of the sensitivity and tune-ability of the proposed magnet designs. This effort should be followed in the test phase with a comparison of the measured behaviors to computations.

Along the same lines, these IR magnets are likely to be subjected to very high heat loads from beam losses. Hence, some thermal analyses should be carried out in order to determine residual coil temperature margins and to ensure that enough cooling channels have been provided for or can be provided for in the magnet cold mass to extract the deposited power without impeding its mechanical integrity.

As already pointed out in previous reviews (but not yet reflected in most of the speakers' talks), the TQC and TQS designs not only differ in their 2D mechanical designs ("collars" versus "keys and bladders"), but they equally and as substantially differ in their 3D magnet ends' design and in the treatment of the axial support. The committee feels that it would help to make a clear and apple-to-apple comparison of the end designs and to envision the required tests and analyses that will be required to reconcile or choose between these two very different approaches.

Up to now, the TQS design was advertised as offering a better control over pre-stress application. The analyses that were shown during the review indicated that the TQC design may not be as critical as originally thought in this respect and that the main difference between the two now resides in the fact, for the TQC, the pre-stress is applied at room temperature, while for the TQS, it shows up during cooldown. Full proofs of these two designs may require a long term creep/stress relaxation study on the TQC design to ensure that the high pre-stress remains more or less constant over time, and an extended test cycle on the TQS design, including a number of cooldowns and warm ups, to ensure the reproducibility of the stress application in the cold state. Also, a detailed pre-stress sensitivity study should be carried out for both designs to compare them and see how critical they are to variations on coil sizes or mechanical tolerances and how easy it is to detect and cope with such variations during the assembly process.

The committee feels strongly that in order to carry out meaningful experiments, there should be clearly documented baseline designs for both the TQC and the TQS series. The number of variants with respect to the baselines should be kept to a minimum within each of the series. Likewise the variation in designs between the two series must be minimized. It is of the utmost importance that the proposed variants go through some sort of a review process and be agreed upon by the collaboration and that there be a clear evaluation of how well they fit within the overall development plan (do not rush to implement a variant on the sole purpose to stay within schedule if it is not meant to become a permanent feature on subsequent models). The committee also recommends that there be a simple table keeping track and summarizing all these variants.

The TQ coil production strategy (and the sharing of tasks between Fermilab and LBNL) appears to be successful. Travelers and Documentation are very important, and a continuous effort should be maintained to keep them up to date. The committee encourages the LARP management to ensure that all technical documents are stored and archived in the centralized database at Fermilab (the responsibility may be delegated to Level 2 managers).

Control of coil sizes is a critical issue for stiff, resin-impregnated Nb_3Sn coils (in comparison to soft and more forgiving polyimide-insulated NbTi coils). The committee strongly recommends that all coils be systematically measured and that discrepancies be thoroughly investigated and corrected. Experience tells us that if not assessed "on line," this problem always comes back and beats on you (and can introduce changes on subsequent assembly phases that may introduce unnecessary variants in the development plan).

Both TQC and TQS programs have or are planning to build mechanical models. The committee feels strongly that these models should be as representative as possible of final assembly procedures and that each experiment should be carefully and thoroughly designed, carried out and analyzed (it is better to "waste" time on these trials that on the final thing).

As there are significant uncertainties on the determination of cable critical currents (in particular when compared to NbTi cables), the committee recommends to put suitable error bars in the customary "I_q/I_{ss} versus quench number" plots. Also, temperature margins plots may be relevant to assess the performances of Nb_3Sn magnets (for instance, in comparison to NbTi alternatives).

To confirm coil temperature margin computations (in particular for the midplane turns), it could be nice to record a complete set of ramp rate and AC loss data on at least one model magnet (possibly in superfluid helium).

It could be useful to name a "magnet mother" physicist for each model, as was done at the time of SSC/CDG. The magnet mother would be responsible for coordinating the work of production engineers, for gathering all data (from assembly to test), for coordinating data analyses and for producing a final report.

At some level, design choices become a religious matter (see horizontally versus vertically split yoke designs for SSC or aluminum versus stainless steel collar designs for LHC). It is likely that both TQC and TQS designs can be made to work. Then, on which grounds will the choice be made and, most of all, agreed upon by the collaboration? It might be wise to include some field quality consideration in the decision making process. It may also be worthwhile to plan for a Technical Design Review to ratify the final choice.

The committee wishes to endorse the recommendation made in earlier reviews that the HQ program be treated as a scope contingency and that LARP should only proceed with it if the LQ program is well under way and will not be adversely affected in terms of resources by the pursuit and extension of the HQ activity.

The committee recommends that the new scope proposal on radiation hard materials be considered seriously for it may become a critical issue for LHC IR upgrade. On the other hand, it recommends that other scope proposals, which are not directly connected or natural extensions of the present LARP magnet program be given very low order of priority so as to prevent scattering of already scarce resources.

Last, but not least, the committee wishes to re-emphasize the importance of maintaining very close ties between this part of the program and the LR and LQ parts of the program. The design parallel between the TQ and LQ series is quite obvious; it is important that the relationship with the LR series should be as tight, in particular regarding the coil production tools which should be designed according to the same concepts as those applied to the TQ series magnets (at least for SRS02 and LRS02).

Long Quadrupole Magnets Program

The long quadrupole magnet program is planned to be accomplished by 2009 to become the base of technical choice for further development of the full-scale prototype for the LHC luminosity upgrade quadrupole

The development of the long quadrupole (LQ) is designed to demonstrate the technical ability of the LHC luminosity upgrade with the field gradient > 200 T/m with an aperture of 90 mm, a length of ~ 4 m (corresponding to a half of the full scale magnet). The committee encourages the plan to be carried out in highest priority, with well considered cooperative plan amongst three institutions of BNL, Fermilab and LBNL.

The program is proposed in two stages consisting of (1) the long racetrack magnet with aluminum shell (LR) as the extension of the short racetrack magnet (SR) program and (2) the long quadrupole with cosθ coil (LQ) as the extension of the technology quadrupole magnet (TQC and/or TQS). The committee supports this cautious technical approach to realize the quadrupole magnets of 3~ 4 m, assumed to be a half scale in length to the full scale prototype magnet to be considered in a further step, after technical choice, beyond 2009.

The committee agrees that LR program should be carried out to demonstrate the length scale-up with the simplest extension of the SR program, and prior to the LQ program. The LR program may yield much important information especially on longitudinally integrated thermal expansion/shrinkage characteristics etc.

The LR program shall be carried out as fast as possible at BNL based on technical experience gained from the SR program and transferred from LBNL. On the other hand, the committee considers that the intellectual contribution at BNL with scientific staff is very important especially to understand the length scaled-up magnet, in mechanical design/performance as well as the excitation/quench characteristics and protection.

The applicability of the highly instrumented LR test to the LQ program should be confirmed before proceeding. If applicable the test could be very important.

Along the same lines, and as the LR program is meant to feed and serve as a test bed for the LQ program, it is of the utmost importance that the Fermilab tooling and production engineers involved in the LQ program keep a very close eyes and collaborate actively with their BNL counterparts (this could be carried out through Production Readiness Reviews before the procurements of the main LQ tooling are sent out).

The committee considers that the LQ program shall be carried out with reflecting well the experience from the short model programs (SR, TQS/TQC) and the LR program as proposed in the general scope of this R&D program. Some concern was expressed by committee members that the LQ-program presentation seems to be rather isolated from the basic R&D programs. The fundamental design conditions such as the cable and the cross sectional design of the TQ magnet should be kept and the length-scale up should be focused to develop the LQ to make the length scale-up effect to be clearly evaluated. In other word, the R&D program should be clearly "traced".

It may be important to have the technical strategy of the extendable length scale-up to the full-scale prototype (6 m or more), which may be twice longer than the LQ magnet. From this viewpoint, the LR should be developed in this concept. The single unit (3.6 m long) keys and bladders may be considered as well as the Al shell already proposed with a single unit. It may be important to watch the length scale-up effect and its expendability to be twice.

It should also be important that the magnet structure shall provide the cryogenic pressure vessel with reasonable technical efficiency (shell acting as the pressure vessel including the axial end structure), and the shell design should be carefully optimized for this function.

It may also be important to demonstrate the reproducibility of the LQ magnets, and two LQ magnets should be the minimum to be developed, and they shall be developed as identical as possible and be tested to evaluate the performance reproducibility including the field quality.

The committee strongly supports and encourages the LQ program to be accomplished by 2009. However, the plan seems to be very optimistic. It should be emphasized that the R&D effort must be well concentrated to evaluate the length scale-up effect, and not to intend to the highest performance with the LQ program. In this view, the change of the design should not be considered and, it should be minimized even if it was inevitably required.

The cooperation amongst the three institutions should be inevitably important. During the review, the committee was impressed with the teamwork shown. It is hoped that this team approach will continue to reach the very important goal of the LQ program.

New initiatives

This list serves as a good pool of candidate projects in preparation for post-commissioning LARP activities. While not all topics on the list are of equal urgency and readiness, the Committee suggests that a concerted effort be made to evaluate these initiatives soon enough so as to allow a good post-commissioning program for LARP. This evaluation effort should not affect in any way of the on-going commissioning programs, but on the other hand, sufficient homework must be invested for each initiative if it is to be evaluated properly. The total amount of work is not to be underestimated and should be planned so as to be consistent with the scope of work at present.

- AC dipole
- Synchrotron light based diagnostics
- Extension of collimator jaw damage studies
- Crystal collimation
- Longitudinal Density Monitor
- e-lenses for Head-on B-B Compensation
- Crab cavities
- analyses of magnetic measurement data during magnet ramping
- Optical stochastic cooling (MIT proposal to NSF)

All of these topics have a pretty good potential for improving the LHC performance. A team has already been formed to consider which new topics should be added to the LARP effort. It should be emphasized that none of the new tasks should be done at the expense of current unfinished tasks. However, a lively discussion of new tasks is most helpful for continued success of LARP.